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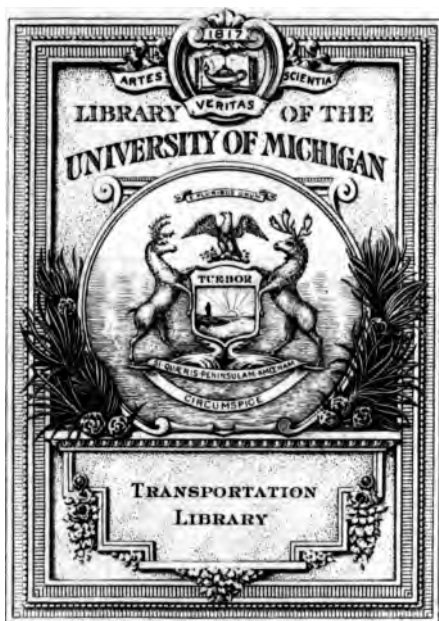
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RAILROAD ECONOMICS;
OR
NOTES, WITH COMMENTS,

*FROM A TOUR OVER OHIO RAILWAYS
UNDER THE HON. H. SABINE, COM-
MISSIONER OF RAILROADS
AND TELEGRAPHS.*

By S. W. ROBINSON, C.E.,

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P R E F A C E .

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A LAW of Ohio makes it the duty of the Commissioner of Railroads to inquire into the safety of the means employed in railway travel. To this end an inspection service has been organized, which aims to examine and report the condition of all the railroads of the State. While engaged in this duty the following items of information have been gained.

Though the immediate object of the service is, if possible, to increase the safety of travel by detecting errors of judgment, seeking out any oversight of defect or weakness that may by any means have occurred, and to extend a uniform system of examination of actual working conditions to all the roads of the State; yet the good opportunity furnished for general

observation that may be made subject of comment and discussion, it is believed, should not pass unimproved.

The present paper has this object in view. Without aiming at criticism, it seeks to bring out such facts, and call attention to such features of railway practice as shall assist the different roads of the State in an effort to arrive at a uniform standard of excellence.

It is believed that a service of this kind should not in its operations be narrowed to the mere matter of inquiry into the condition of safety of existing structures and appliances; but also to seek to indicate from among all observed the most useful and economical forms of those appliances, or such as shall in the long run result in the greatest safety for a given expenditure.

For instance, that form of bridge structure for general use for short, for moder-

ate, and for long spans, which is safest not only when new but during a reasonable length of life; the real cause and magnitude of the "dynamic effect" and means for reducing it; causes of peculiar and accidental vibrations in the vertical and horizontal; deterioration of iron and steel in use by annual observations for gradually increasing permanent deflection of bridges of those materials; the most useful forms and combinations of parts constituting the track line; the best forms of important subordinate structures; the best systems of signal and operating appliances, &c., are believed proper subjects of investigation and study by this service.

Indeed railroading illustrates perhaps better than anything else the fact that this is eminently a mechanical age. Everything now-a-days is done by machinery, even traveling.

The railroad system is an immense traveling machine, and not only because an affair of such tremendous magnitude, but because it involves to such an enormous extent the lives of human beings, its means and methods deserve the most careful and extended examination and study. And it is believed that Legislatures, and even Congress, can do a valuable service in instituting means to this end. S. W. R.

COLUMBUS, May 13, '82.

Railroad Economics, or Notes and Observations
from the Ohio State Railway
Inspection Service.

TRUNK AND OTHER LINES.

In Ohio, as well as in at least two other States, there appear to be two classes of railroads,—first, the great trunk lines connecting the West with the East, and, second, those having largely or altogether local interests. The former are most likely to run east and westward, while the latter run mostly north and southward. Strong companies control the former, while the latter often fail to pay well enough to keep up repairs. In many instances a weak company sells its interests to a stronger, when the former causes a general need of repairs. The strong company or trunk line then puts the road into good running condition, sometimes to form part of a through line, sometimes a branch, and

sometimes to form a tributary to it. In this way a road of secondary importance may be kept up to good running condition, while otherwise it would go down.

Whatever may be said against consolidation of railroads, it appears to be a fact that roads owned by strong and wealthy companies are in far better condition than otherwise. Indeed the generally good condition of the great trunk lines and of their branches is a credit to those companies. If these roads are backward in some things, such as introducing the best systems of "signaling," "blocking," and of "interlocking apparatus," they are certainly up in other matters, such as steel rails, iron bridges, &c.

SAFETY.

A little attention to railroading will suffice to show that safety in railroad travel is the price of incessant vigilance. That a stretch of three hundred miles, extending across a state is, every foot of it, perfectly safe to-day, is not proof positive that it will be so to-mor-

row, though the broken rail or washed culvert is the subject of constant search.

PROTECTION OF RAILROAD STRUCTURES.

The life of railroad plant is not great. New roads, with iron rails and wooden structures, will need renewals for the most part within ten years. Rails endure according to traffic, and for light traffic will run ten years. Ties will rot out in from five to eight years. Culverts, cattle guards, &c., about the same. Good wooden bridges, when new, will be dangerous in ten years unless covered. If covered at all it should be done within two years after building, otherwise the timber becomes affected with dry rot at the heart. This decay might perhaps better be called *blind rot*, because it is hidden. A wooden bridge, nicely covered and painted, may *appear* to be in the best of condition, but really be in the very worst. Joints in the lower chord of such bridges are seen to be pulling out by the locks splitting off. In such cases, when the timbers are sounded with a boring bit

the latter will find sound wood for two or three inches, when suddenly the bit may take a jump of four or six inches through a dry rot hole. Such well-covered and well-appearing bridges are found not to have been covered under about three years after building. Equally good uncovered bridges, even better, ten years old, have been found than those of equal age, well covered, in which the covering was delayed three years. It appears that after three years of exposure to open weather, a bridge is doomed to a life of only about ten years covered or uncovered.

But by prompt covering of wooden bridges the life is more than doubled, from which it appears that the practice of covering such bridges is highly economical.

It is sometimes the practice to cover simply the trusses, and it is necessary in "half Howe" or "pony trusses of wood. This leaves the floor system exposed, and any sap wood about the floor-beams or the stringers is soon eaten away with decay. Sap is of but little worth after

three years' exposure, even when free. But heart wood is often perfectly sound at ten or fifteen years. Sap wood is so comparatively worthless that some engineers specify that not over eight per cent. of section of timbers shall be sap. It is an excellent precaution to thus limit the sap wood, because it is practically of no value. In existing bridges sap wood rot has reduced the section of chords, as estimated, from ten to twenty per cent., the remainder being sound. Uncovered flooring should, therefore, be watched, and when the beams are found weak, as by observed excessive deflection, new beams should be added.

Painting is an excellent practice, and its power for prolonging the life of wood is not confined to free or external surfaces, but internal as well,—that is, to illustrate, lower chords have been examined where the wooden "clamps and keys" were laid in white lead, or sometimes in red lead, and such are sound and strong to a greater age than unpainted.

A close joint in wood, where exposed,

is far worse than open joint of small space sufficient for air to pass. From this fact it appears that wood contacts have been avoided by using iron "clamps and keys" in lower chords. Some engineers make iron clamps or blocks with a space for ventilating between wood and iron, the bearings being quite narrow. These have given good results, and point to the value of ventilation.

As to ventilation in general, all coverings should leave the main bridge timbers free for air to circulate about them. For instance, the boarding along the sides of trusses should be firmed out by girt strips being nailed to the truss along the braces above the lower chord and below the upper chord, and not on the chords themselves. Then, when the boarding is nailed upon these girts, it stands out free, so that air can freely go all about the chords.

In some instances chords have been found covered with tin, the same being fitted about the braces and nailed to the chords, so as to appear like giving pro-

tection to the chords beneath. But this is believed to be worse than no covering whatever from the simple facts that, first, water will work in at the numerous joints, and, second, be held there by the tin covering. If the tin could be carried away from the wood by a 2" space, the latter being allowed for ventilation, it will serve a good purpose when it is made tight. These conditions are readily met in "combination" bridges, that is, in such as have wood upper chord braces and end posts, but with iron ties and lower chords. The upper chords are readily covered with tin, because nothing protrudes above to prevent. The braces, or vertical pieces generally, do not need covering, as it is found that the wet so rapidly escapes as to leave the braces soon dry.

Special pains should be taken to keep wet out of close places in wood. For instance, in deck bridges (Howes), water is apt to leak through the roof, as it is difficult to lay a roof among the ties, floor beams, string, &c., in the floor sys-

tem and get it tight. In such cases the sway braces are apt to carry the water which falls upon them down upon the lower chord. This has been avoided very neatly, cheaply, and efficiently on the Lake Shore & Michigan Southern Railway, by making a saw cut across the top and edges of the sway braces, and driving in a collar of sheet iron or tin, which extends down like spurs below, and thus heading off any water which may find its way through the floor or roof above, and alight upon the sway brace to come trickling down upon the lower chord.

But though tin may be suitable to cover upper chords as above explained with reasonable durability, yet as a main roof covering over the tops of Howe bridges it appears to be utterly worthless, for the reason that the sulphurous fumes of the smoke from the locomotive soon eats the tin roof through like a big pepper-box lid. Indeed this action has been observed upon heavier masses of iron than tin; the truss rods even

having been observed in badly rusted or pitted condition, with a weakening of probably five to ten per cent. The latter has been observed to be most serious in low lands, such as would be frequented by fogs. The moisture of the latter deposits upon the rods and absorbs the acids of the smoke. The iron is then etched more or less seriously. Rods for such localities should be made with some excess of section to provide for the corrosion.

WOODEN BRIDGES.

The prevailing wooden bridge is the Howe truss. It consists, as generally put up, of an upper and lower chord, connected by vertical tie-rods running through with nuts at both ends; the latter dividing the span into panels containing braces and counter braces. The chords usually are made of four sticks, side by side, with blocks or "keys" notched in, but leaving a space between all the sticks. Chord bolts run through from side to side of chord to draw all together. In short chords the

sticks run from end to end. But *for* lengths greater than about forty feet, pieces are put in so as to break joints. In upper chords these simply abut against each other, but in lower chords, clamps are used to make tension splices. These clamps are generally of oak wood, and preferred by some builders of the first and by some of the second form in Fig. 1. Sometimes only one is used to a

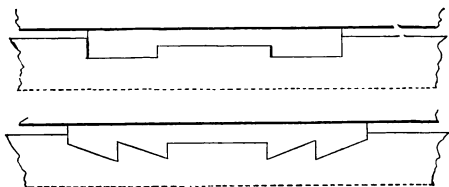


Figure 1.

splice, as shown, but more often two, one on each side of pieces joined. A chord bolt goes through near each end of a clamp. The earliest point of failure in a wooden bridge is at the locks of these clamps, either on the clamp itself or on the interlocking hooks of the chord.

Two of these splices are never found opposite in a chord, but break joints, so as to allow one joint to each panel. In this way the so-called keys help to form the splice. There are always two main braces and one counter brace between in each panel. The former always incline toward the middle span point. In moderate spans there are always two tie-rods at each inter-panel point, but in long spans there may be three at the ends of truss. The largest of these rods are 2" in diameter; almost always threaded without enlargement of ends. These ties draw against straps on the outside of the chords, running from 1" \times 5" down to $\frac{1}{2}$ " \times 3" in section, and long enough to extend the width of the chord. The braces almost always set square against iron angle blocks. The best of these blocks have flanges to prevent the braces from falling out of place. These blocks are often found broken, but the breakage is evidently due to carelessness in drawing up the tie rods too tight upon the braces, because on some roads these

breaks are very numerous, while on others the same make of blocks are never found broken. Road masters say they find difficulty in getting men to draw their ties up properly upon the braces.

The depths of these trusses vary. Short spans, or "pony" trusses, sometimes also called half trusses, run from about eight to twelve feet height. Full trusses for longer spans are usually about twenty feet. The smaller trusses have about three or four floor beams per panel, while the larger have five. They always rest upon the chords.

When wooden bridges show signs of failure the speed of trains is often reduced till a remedy is applied, either in strengthening the bridge or by renewing it. Two ways of strengthening a lame bridge are in use. One consists of springing a wooden arch from the abutment, usually from iron skewbacks, placed about six feet down, and rising at mid-span nearly to the tops of the trusses. Each case requires four arched ribs, one on each side of each truss. From the

arches the trusses are suspended by rods. But this method is too expensive for an old bridge; it is more common for a light bridge otherwise good. The second way to doctor the bridge, and which is very common for old bridges, is to put a trestle bent under at the third or quarter span. A pile bent is sometimes used instead of a trestle bent. The objection to placing the bent at the middle is the fact that the counter braces near the middle in that case become main braces. Some less considerable road masters place the doctor at the middle, however. But as the carrying power of a truss varies inversely as the square of the span, other things being equal, it appears that the strength of a bridge is nearly doubled by placing a support at the one-quarter point. Such trestle bents are carefully watched to guard against washing out by the stream. In high water such a trestle bent is a treacherous affair, a pile bent being far preferable.

The lateral bracing in bridges is almost

always about the same, viz., about 6×6 braces and $1\frac{1}{8}$ " tie rods, and the same from end to end of bridge. These are usually in the plane of the lower chords and also upper. No difference is made in the strength of the lateral bracing, as far as observed, for straight or curved track, though it is certain that the centrifugal force of a train running on the curved track over a bridge will give cause for lateral thrusts, which are considerably greater than for straight track. One element of compensation, however, exists in the fact that bridges under curved tracks are usually wider, so as to allow equal clearance room, and this gives wider lateral trussing. Trusses are not found inclined on account of curves on the bridge.

Through bridges of wood have no "sway" bracing. The chords of the trusses are from 24" to 30" in breadth, and the floor beams extend entirely over to the outsides. This keeps the lower chord in position. The braces cover about the whole width of the chords, so that the trusses are quite stable in erect position.

Deck bridges always have sway bracing, but in some cases much stronger than others. Where several spans of wood bridges are contiguous, in some cases both or all are made continuous from span to span. In other cases only one chord will be continuous. Diagrams taken, as hereafter explained, have shown that in continuous two-span bridges an appreciable rise of the second span occurs when the train gets fairly on the first.

IRON BRIDGES.

The prevailing form of iron bridges is the Pratt truss for long spans, and for short the plate girder. The change from one form to the other occurs usually at lengths between sixty and a hundred feet. These statements apply more definitely to recent practice than former. The older iron bridges are very promiscuous, both as regards form and manner of putting together. Some of the first iron bridges in the State were Howe trusses, one of which went down

in the Ashtabula disaster. But in place of the latter we now find what is probably the strongest iron Pratt truss in the State, so that people need not now go around Ashtabula to avoid a second catastrophe.

The parts of truss bridges were formerly united in various ways, sometimes by bolts, notches and locks, and often by riveting in place. But at present the method by pins and eyes prevails, especially for the longer trusses. In upper chords, however, though the tie rods are usually attached by pins, yet for increasing the rigidity they are made continuous by riveting on splice pieces extending past the pin holes. The forms of parts of bridges, as well as the methods of joining, are almost as though stereotyped. Thus the "eye-bar" is an article of manufacture, and is used in all parts of bridges except upper chords and struts or columns.

Upper chords and end posts are most frequently made of two channel bars, twelve to eighteen inches apart, with

webs vertical. They are joined on top by a longitudinal plate extending the whole length and riveted to the flanges, while the bottom side is latticed or "laced." "Web" members serving as struts are most frequently composed of two channel bars at a distance apart, and connected by diagonal lattice slats riveted on. Sometimes, however, the two channel bars are riveted by their webs to the flanges of an I-beam. Formerly Phoenix, Keystone, Box and other columns, nearly or quite closed, were much in use, but they appear to have given place almost entirely to such open columns as above mentioned, simply from the necessity experience has developed of painting every inch of surface in iron bridges.

Most engineers require forms such that a paint brush can touch every part, either inside or out. The advantage of this is seen from the fact above mentioned of the rusting of truss rods and of tin roofs from moisture and smoke. The statement also, which has come to my notice, that tons of rust have been removed from tubular bridges, is in point.

Floor-beams, made by riveting four angle bars upon the edge of a plate—two upon each edge at opposite sides—are the most common. The section approaches that of the I-beam. Plates are often riveted on top and bottom, part of the length, to increase the strength at the middle part where the moment of strain is greatest. These beams are most frequently suspended from the pins of the trusses by inverted “ Ω ” bolts. But when there is scant room below a bridge for water way or otherwise, they are in some cases riveted to the vertical struts.

The stringers are most frequently of rolled I-beams.

The lateral stiffening is much better attended to in iron bridges than in wooden ones. The lateral ties not only vary in size, from end to middle, but differ in size according to span, width, &c. There is generally a lateral system at both the bottom and top chords.

Plate girders are usually formed by riveting angle bars to the sides of the webs, top and bottom, then across these

a flange. The latter is increased by additional "lifts" laid on the middle portion. These plate girders are usually of uniform depth, though some have been met in which the upper flange or chord was arched so as to nearly join the lower chord at the ends. Vertical stays of angle bars are riveted to the web throughout these girders, but nearest together at the ends, their object being to prevent the buckling of the webs. Most usually the two girders of a bridge are joined by riveting to the floor beams, so that all forms a connected system. An angle plate then is set between the floor beams and girders, to prevent the latter from swaying or careening.

But on some roads many of the plate girders have wooden floor beams; the latter sometimes resting directly upon the lower flanges, and sometimes on angle bars riveted to the girders. A neat and serviceable small bridge, where there is sufficient water-way, consists of plate girders, about ten feet apart, with lateral and sway bracings, and upon which are

mounted the wooden floor beams. This plan is carried down to I-beam girders of ten feet span or less.

In a few instances weak iron bridges have been strengthened by springing iron arched ribs from the abutments, composed of channel iron, and securing the same to the trusses of a suitable number of points.

At the present day many good iron bridges are found to be too weak. This is due not to any engineering defect, but to the growth in weight of freight loads and rolling stock. We now find sixty-ton locomotives where formerly there were forty; and twenty-ton loads per car where there were ten. Hence bridges designed to a strain of 10,000 pounds per square inch of iron section, as due to the former loads, must now stand 15,000, or perhaps more. This is unfortunate, since an iron bridge is so difficult to strengthen in a satisfactory manner, and so difficult for the road men to get renewed.

Expansion and contraction of iron

bridges is provided for in supporting one end on rollers. In short spans, however, rollers are dispensed with, and the bearing plates slide. Often the observed expansion reported by bridge attendants does not account for the whole variation of length, even where rollers are in use. It is believed by some that the rolling resistance under so much weight is so great as to spring the piers where piers are tall. Thus it appears that strains, due to constrained expansion, may be too great upon chords to be ignored in calculating total strains.

STRAINS UNDER MAXIMUM LOADS.

In proportioning the parts of bridges for resisting their strains, a great variety of detail exists in the present practice. We find no "live" bridge engineer of to-day adopting a fixed maximum load per foot for all spans, even for the same road and the same trains; neither do we find the same fractional part of the ultimate or elastic resistance of the iron adopted for the allowable strain for all parts of any

one bridge. The factor of safety is "a thing that was" to such an engineer.

In the first place the quality of the iron is allowed to differ for different parts of bridges. Tension members are never made of anything but "double-refined" iron, that is, iron that has been double rolled. This consists of taking "muck-bars" (the result of first rolling from puddle blooms), cutting and piling them, reheating to a welding heat, rolling into bars, then cutting, piling, and reheating again, when they are rolled to the needed sizes. Compression pieces are single refined, in which the last piling and rolling above described is omitted. Channel bars of columns and upper chords are thus treated.

A fair quality of double refined iron in bars should have a tensile strength of 50,000 pounds per square inch; an elastic limit of 26,000 to 30,000 pounds per square inch; should stretch fifteen per cent. in eight inches; bend 180° around a cylinder of diameter equal its thickness without fracture; and when knicked and

broken should show a fibrous structure. Such iron in the regular truss tension members is usually allowed to be strained to 10,000 pounds per square inch for the maximum load. In some cases floor beams are allowed 8,000 pounds only, because they are strained nearly to the maximum allowed for each passage of load. This is true of floor beams, because the greatest load occurs when under the drivers of the locomotive. In the main truss, however, the maximum strains are only reached when the whole train is up to the maximum, a condition which does not happen with every train. The Ω shaped hangers for floor beams are usually allowed only 5,000 to 7,000 pounds. Struts and upper chords are computed as columns, and on a supposed basis of about 8,000 * pounds square inch. This low value is probably partly due to the fact of single rolling for channel iron.

* By a rational formula for columns, published by the writer since this paper was presented to the Society, it is shown that this value should be but a little over 6000 pounds. (See VAN NOSTRAND'S ENGINEERING MAGAZINE, for June, 1882.)

ASSUMED MAXIMUM ROLLING LOADS.

In calculating the maximum strains there are two ways of treating the question of the maximum load.

1st. By adopting the greatest actual train weights, such as two of the heaviest locomotives, followed by a train of the heaviest loaded freight cars; then computing the strains as static effects to which results are added, for "dynamic effect,"

For spans of about 30 feet.....	25	per cent.
" " " 50 "	15	"
" " " 75 "	10	"
" " " 100 and over...	0	"

2d. By assuming fictitious train weights which are uniform per foot for the span, but which are much the greatest for short spans. Thus, for some roads on this plan, the assumed load for calculating strains is:

For spans of 10 feet....	6000	lbs. per foot.
" " 40 "	4000	" "
" " 150 "	3000	" "
" " 200 "	2500	" "

This diminishing scale is to be accounted for as providing, first, for impact; the latter being greatest for short spans, because so much more quickly passed by the forward end of a train, and causing an application of load which is so sudden as to be of the nature of a blow; and, second, because short spans have the locomotive itself for the maximum load, while longer spans can only be covered by adding to the one or two locomotives, some portion of the train.

CRYSTALLIZATION OF IRON IN BRIDGES.

As regards the deterioration of iron in use by crystallizing, there are differences of opinion and two few facts. One man will present evidence of crystallization, while another will produce equally good evidence against it. It appears that data are too uncertain. When rods taken from a bridge are found to be crystalline, it is not known whether they were not so when put in. But this matter will be settled in due time, because positive data now exist as to the condition of iron in

existing bridges. When the future engineer shall examine the parts of these bridges, and compare notes with the former records, we shall know how about crystallization.

STEEL BRIDGES.

We are now at the verge of a steel bridge era, several important steel bridges being already built, and in process of construction. The most important mechanical difficulty in this direction is already overcome in the existence of machinery, for the manufacture of solid steel eye bars. Steel is in every way better fitted for bridges than iron. It is less subject to deterioration, becoming more uniform in results of manufacture, has an ultimate strength of nearly double that of iron, and an elastic limit from two to three times as high. Considering the strength, it is but little, if any, more costly. This step from iron to steel is but the natural course from cast-iron up, which latter material is now entirely abandoned as a material for

bridges, except for unimportant members, such as wall plates, packing pieces, etc.

SWAY BRACING.

In both wood and iron bridges "sway" bracing is universally employed in deck bridges. But such bracing is held in doubt by some, except at the ends of the bridge, where it should be especially strong. The reason given for this belief is that where one truss receives a greater strain than the other from any such cause as wind against the train, train at one side, as in double-track bridges, curved track, etc., each truss should be allowed to remain in a plane. But the sway braces preserve the cross section, so that if one truss deflects more than the other, each truss must careen to one side to some certain corresponding extent at the mid-span, but not at the ends, because here the solid abutments prevent. This forces the chords laterally out of a straight line, causing horizontal transverse strains upon them. The eye bars on one side of

the lower chord would, under these circumstances, be strained more than those on the other side, an inequality which would disappear in the absence of sway bracing. Not only would the main trusses be affected, but the lateral bracing at top and bottom would be strained unduly, and probably higher than provided for in the oversight of this matter. The old Ashtabula bridge was an iron deck, and who can say to what extent the sway bracing were responsible in the failure of it ?

Though the one consideration of greater flexibility of cross section seems to favor the omission of sway braces, in that we thus obtain freedom from stresses in one system of bracing as due those in another system, yet it is probable that the yielding cross section will allow the train, while under wind pressure, to be forced to a greater inclination toward the leeward, thus causing a probable greater displacement of the center of gravity of train toward the leeward truss, and increasing the strain on the latter.

VIBRATIONS AND STRAINS.

In observing the deportment of a bridge as a swift train passes over, the parts are seen to be much agitated. Tie rods will often fly about at the middle parts to a very considerable extent. This has evidently received some attention by engineers, because in a few instances tie rods at the crossing points have been found tied together apparently to stop vibrations. That all such vibratory movements cause direct strains in the vibrating parts there can be no doubt; and it is unfortunate that these vibrations cannot be predetermined so that the strains resulting from them can be calculated. Could these be accurately determined, it is probable that the practical maximum working stress for bridge iron in tension could be safely raised from 10,000 pounds per square inch to 15,000 pounds; a margin being still left between the latter figure and that for the elastic limit for indeterminate strains due to such movements as considered below.

LURCHING OF THE BRIDGE.

In some cases the whole central part of the bridge is also in an agitated condition, both vertically and horizontally. There seem to be various causes for this, such as want of perfect balance in the drive wheels and connections, error in perfect alignment of rails, especially in the vertical plane, wandering of the wheels from side to side over the 1" to $1\frac{1}{2}$ " of clearance between flanges and rails, irregularity of curves on bridges, tangent points on bridges, etc. In some cases this seems to amount to an oscillatory or vibratory movement of the whole bridge.

A BRIDGE INDICATOR.

In order to study these effects more satisfactorily, as well as the "dynamic effect" of a moving train upon a bridge, an instrument has been devised which might be called a *bridge indicator*, the object of which is to give a graphic record of the movements of a bridge as a train passes it. A rude affair of the

kind has been used with results given below. In this case a bridge near Columbus, Ohio, was chosen as the subject of experiment with the instrument, it being the only one yet experimented with. This particular bridge was a "pony," or "half Howe" truss, of two spans, both upper and lower chords being continuous over the central pier. Each span is 60' 6" long, with a total depth of truss of 8' 9". The chords are of three timbers, 5", 10", and 5" \times 12" in section for the lower, and 5", 10", and 5" \times 9" for the upper chord. Main braces are 6" \times 8", and counters 6" \times 6".

The upper diagrams of 1, 2, 3, &c., were all taken at the middle of the west span of the bridge. The lower diagrams, of the same numbers, were taken at the middle of the west half of the west span. Thus, any two diagrams under one number were taken simultaneously, the upper at the middle and the lower at the quarter of span.

The track on this bridge was straight,

except at the west end, where ten feet belong to a curve of about four degree. Thus, a tangent point lies in about ten feet from the west end. The object of placing an indicator at the west quarter of the bridge was to observe the effect of this tangent point.

A description of the instrument will aid us to a better interpretation of the diagrams. At each point for taking diagrams a wooden board, dressed smooth, was secured to the bridge firmly at one truss. The plane of the board was vertical and perpendicular to the line of the truss. A paper was secured to the board by thumb tacks for each diagram. Upon these sheets while thus tacked to the boards the diagrams were made. At the midspan the paper faced toward the east, while at the west quarter it faced toward the west. From the ground beneath the bridge a stand was built of timbers and brought up to where a pencil could be firmly held by it, and in such position as to lightly touch the paper tacked upon the board secured to the bridge, as above

described. Under these conditions a movement due to the yielding of the bridge in any manner would be indicated by a mark of the pencil upon the paper. A vertical deflection of the bridge would make a vertical mark equal in length to the deflection. Also a horizontal movement would be indicated by a horizontal mark, or, finally, any sort of cross motion of the bridge at the indicator would be evinced by its representative mark. In other words, the bridge autographically registers all of its own transverse movements.

The same figures would be obtained, evidently, if the paper were held upon the stand and the pencil upon the bridge, except one would be inverted with respect to the other. The most natural arrangement is the latter, and for that reason the diagrams are so posed that a downward motion of the bridge is indicated by a downward stroke of the pencil on the figure. The figures are enlarged 2.7 times.

No. 1 was taken at the middle of the bridge when a slowly moving freight



train was passing, drawn by an ordinary-sized locomotive. The pencil was held on the paper till about ten cars had passed going east. The bridge sank gradually from A to C as the engine approached the middle of the span. But as it passed on over, the pencil rose to D, and remained there till about five of the heaviest loaded cars passed. For the lighter cars following, the pencil rose to E and remained there for the next five cars, and it was then removed.

No. 2 is for a freight train going west at about twenty miles per hour. A is the position of the pencil when the bridge is at rest. As the engine came upon the east span the pencil rose from A to the top of the figure, and then de-

scended again to the bottom as the engine came over to the middle of the west span where the indicator was located. Then the pencil rose to the top of the open part of the figure when it was removed, the engine having just left the bridge. The lower part of No. 2, taken at the quarter, had the pencil in contact longer than the upper part; the heavy blotch at the top of the lower third occurring while the cars of the train were passing.

No. 3 resulted from the passage of a passenger train of four cars going west. As the train struck the east span the pencil rose from A to B, but descended as the engine came upon the west span to the lowest point, it then rose to the heavy markings at the middle. Finally the pencil returned to A.

No. 4 is for a passenger train going west. As the engine came upon the east span the pencil left the point of rest A, rose to B while engine was on east span, went to lower part of figure as engine came on west span, but finally returned exactly to A as the train left the bridge.

2



3



2



3



4



5





4



5



No. 5 is for a passenger train going east, four cars. Pencil went down to lower point as the engine was on the west span, then it rose as the second span was reached, and finally went above A to B as the rear of the train was on the east span. But the pencil finally returned to A as the train left the bridge.

No. 6. Passenger train, two cars, going east at about thirty miles per hour. Pencil was removed just as the last car passed it. This explains the absence of the point B. A variety of small movements must have occurred when the pencil was about at the middle of the diagram, thus giving cause for the black blotch.

No. 7 was taken as a pony engine passed very rapidly going east. The pencil was removed as the engine reached the middle of the span. This explains why B is missing. The lower part of No. 7 is a more simple diagram than any of those taken at the quarter, though the pencil was not removed till the engine passed. This is due to the fact that

6



7



the engine was alone. This card gives us a complete loop, the pencil returning to A.

The diagrams from the quarter point add but little interest. They resemble the others both as regards general form and in having two points A and B. They are smaller than the others, but not so much so as would be naturally supposed. They do not add much light respecting the influence of the tangent point on the west quarter of the bridge. Also the relation of the movements of the bridge at the two points does not appear to be systematic in detail, though bearing a general resemblance as above stated.

Much interest attaching to these diagrams is obscured in the knotted points. To remedy this it is proposed to arrange a clockwork to carry the paper forward, at a predetermined speed, while the diagram is making. Then if the number of cars in the train is noted, and if the instant at which each end of the train passes the indicator is marked by a dot on the moving diagram paper, we will,

by knowing the speed of the paper, have data for miles per hour of train, and ordinates for every position of train. But on the paper we should have two curves traced, one for the the vertical movements of the bridge, and one for the horizontal. This would give us the means of completely analyzing the obscure parts of the diagrams.

Simple lurches would be indicated by irregular sinuosities without law, while for vibrations they would be systematic.

One drawback to the general applicability of this instrument would be found in the inconvenience in erecting the tower for carrying the pencils. As a substitute for the tower, it is proposed to throw out a stone anchor from the desired point of application to the bridge, the anchor having attached a hempen cord or fine wire long enough to extend up to the point of observation. A pencil is then to be arranged in a slide working freely in vertical guides, to which slide the wire is to be attached. A spring, quite flexible, is then to draw up

on the slide making the wire below tense. Then as the bridge rises or falls the wire causes the slide to remain at a constant height, while the instrument and paper are vibrating with the bridge. It is then only necessary to place the pencil to the paper, and the clockwork in motion, to secure the diagram for the vertical movements.

The lateral movements are not quite so easily provided for since there is need of an anchorage at one side on a level. It is believed, however, that this can be secured in effect by two anchors and chords, the latter forming a junction at the horizontally opposite point desired. To hold them, a tension stand under spring action, drawing as a resultant force to the two anchor chords, will fix the junction point as desired. In case of such double anchorage to the lateral and vertical, two pencils may be made to write on the one sheet or ribbon, and thus one clockwork answer the purposes fully.

Such an instrument with conveniences



for anchorage could be applied to a bridge in a few minutes, and inspectors could obtain an autographic record of the degree of agitation of any and all bridges examined.

Such diagrams would evidently throw much light upon the vibratory effects due to unbalanced locomotive drivers, and indicate whether cumulative impulses from such parts of the train ever cause dangerous vibrations of whole structures.

INDICATED DYNAMIC EFFECT.

The diagrams presented are not sufficient in themselves to serve this purpose fully and satisfactorily. Their appearance might, however, suggest some amount of vibration or oscillation. Referring to No. 7, first part, remembering that the pencil was removed as soon as the engine reached the midspan, we observe some evidence of lateral vibration as occurring simultaneously with the sinking of the bridge. But as to the vertical movements, we see almost no

trace of repetition of any part of the movement as would be likely to occur if the bridge vibrated in going down, except, perhaps, in a slight degree in the loop in the bottom. This loop is about one-eighth of the depth of the diagram. The lower part of No. 7 indicates almost no vertical vibration in any part. Loops at the bottom of Nos. 6, 5, and 4, indicate vertical vibration, also of about 22, 14, and 10 per cent. of the depth of the diagrams respectively. Taking a half of these amplitudes as the increase of deflection due to dynamic effect, and comparing with the diagrams diminished by the same, we obtain the percentage which the dynamic is of the static effect, as 7, 12, 8, and 6 per cent. respectively, as due to the above measurements. Some of the lower diagrams give evidence of about the same percentages. The mean of these percentages is only about half what is required by some railway companies to be allowed for spans of the same length, viz., 60 feet. As given above in speaking of usual practice in

this matter, it is about 15 per cent. for 60 feet spans. But it is always necessary to provide not for average, but maximum stresses in such cases. Hence the maximum 12, is close enough upon the 15 of practice.

Nos. 1 and 2 are both from freight trains, and give evidence of almost no vertical vibration. Also the total deflections, counting from the points of rest A, are less for the freight trains than the passenger trains in Nos. 3 to 6. If, however, we add the above twelve percentage of dynamic effect to the deflection in Nos. 1 and 2, we obtain very nearly the same strains as are actually due to passenger trains; and singular enough, as obtained in actual practice by computing static effect of freight trains and adding the stated percentage for dynamic effect.

These facts, though corroborative of the real existence of dynamic action or impact, yet at the same time they testify to a somewhat excessive allowance for it by practical engineers. But before drawing conclusions in this way for guiding

us in practice, it is necessary that much more extensive data be procured and worked up.

As regards lateral vibration, the first two numbers on the plate are narrower than the rest, the same being taken from passing freight trains. The others are for passenger trains, except the last one from a rapidly moving pony engine. Hence it appears that fast trains cause much the greatest lateral disturbance. The resulting effect upon the lateral bracing is a matter of interest. By measurement of the widths of the diagrams taken at the midspan, it is found that the total lateral movement for passenger trains is 42 per cent. in excess of the like movement for freight trains. May not this call for careful attention to the subject of dynamic effect upon lateral bracing?

TESTING AND SELECTING MATERIAL.

In the selection of material for bridges, great care is exercised by bridge companies, much greater, indeed, than is

usually supposed by the mass of people who ride over their bridges. Some bridge companies make tests of the materials not specified or required by the railway companies ordering. For instance, the Detroit Bridge Company examines all the eyebars for a bridge by piling a quantity of them and passing the pin through the eyes at opposite ends simultaneously. Any bar preventing the passage of a pin is thrown out. Then the bars are individually tested to a tensile strain of 15,000 pounds per square inch, and again the pins must similarly pass. If any eyobar has stretched so as to prevent the passage of the pin it is rejected. Such a practice would discover hidden flaws, and would pay if discovering such flaws only at the rate of one in a hundred bridges. A flaw which would probably have been made known by such a test was actually discovered by the road master of the Baltimore & Ohio Railway in one of his iron bridges, and the piece had to be removed. A first-class catastrophe might have here re-

sulted except for the keen eye of the road master. There are those who object to straining iron going into a structure, especially beyond the working load. But a test which will discover the few hidden flaws that would otherwise pass unobserved, will probably more than offset imaginary evils due to strains which, though within safe limits, are somewhat in excess of the adopted working load. Accordingly, this test is believed to be a most excellent one, but of the few bridge companies conferred with in regard to it by the writer, it has been found in use only in the one instance named.

All companies do more or less testing with testing machines, including pieces ranging from small "test specimens" to full-sized bridge members. Tests for tensile resistance are by far more plentiful than compressive, but a good number of the latter are on record including full-sized bridge columns. It is a quite common practice, however, to test a piece taken from a large bar rather than the whole bar itself. Large bars are thus

found to have a lower tensile strength than smaller rolled bars.

Testing-machine tests for tension, to meet the present demands of bridge builders and companies, must make known at least three quantities :

1st. The elastic limit.

2d. The ultimate strength.

3d. The percentage of total elongation of some specified portion of the original bar—usually about eight inches.

In some cases the greatest reduction of section is noted, and by some this item is preferred to the percentage as above.

As regards the elastic limit, it is found not to be perfect, that is to say, some permanent elongation is always experienced by good iron before arriving at what is usually adopted for that limit. But practically these elongations are nearly proportional to the increments of load, and extend nearly through the whole range of loading up to the so-called elastic limit. Beyond this limit, however, they rapidly increase. The point where this change takes place is

noted as the elastic limit. This limit, thus found, is given a more rational showing from the fact that, if at any point within it, the strain be relieved and then restored, no further permanent elongation is experienced till after passing the previous condition of strain. At points beyond the elastic limit, however, this is not the case. An extended examination of iron specimens will verify the following facts:

1st. Bars immediately from the rolls, which have not been subjected to jars or other causes of strain, will experience permanent elongation at very slight tension. This is true also of bars direct from the annealing oven, even though they had previously been subjected to violent mechanical action. In these cases there appears to be no limit of perfect elasticity.

2d. A gradually applied and removed tension within the usually accepted elastic limit produces a permanent elongation, which will not be increased for like

or less tensions as above stated. This is also true of compression.

3d. A specimen which has been strained, as indicated in 2d, will take a permanent set for a slight reversal of the strain.

4th. At the point where the permanent elongations cease to be nearly proportional to the increments of load, or to the elastic elongations, we find the usually accepted elastic limit. Some of these facts can be verified by simply straining a piece of annealed wire by hand.

But the most common tests in use among bridge builders, and which are at once both invaluable and fortunately of easy application by any blacksmith, consists,

1st, of bending a bar 180° degrees around a cylinder whose diameter equals the thickness of the bar, and which the bar must stand without fracture to be accepted;

2d, of nicking a bar on one side with a cold chisel, and bending it similarly as in 1st, with the nick at the bow of the

bend, when it will usually break, showing a fracture which must be fibrous and free from glistening points or faces. Very frequent use is made of these tests in the smiths' workshops where waste pieces of bar ends, which have no other value except for scrap, are put to a most valuable service.

HEADS OF EYEBARS.

In the manufacture of one very important part of iron bridges, viz., the eyebars, a number of methods are in use. One consists of forming the heads by a separate operation, and then welding them upon the bars. The weld is made close to the head without upsetting the bar near the welding point. This must certainly reduce the sectional area of the bar at points so near the weld as to be heated but not worked, because the heat cannot be taken without corroding the iron, and thus eating away a small portion. But where full-sized bars of this kind have been tested to destruction, it appears

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that the rupturing point is always at some intermediate part of the bar considerably removed from the head, thus proving the reduction by burning to be unprejudicial. This practical ignoring of the slightly reduced end sections appears to be due to the influence of the enlargement of this head. This conclusion is verified by experiments in tension on extended necks of wrought iron, the fracture always occurring at some intermediate point in the neck.

In other cases heads are formed on the bars by welding several thicknesses of iron upon the side of the bar, thus giving a sufficient body of metal to form the eye. The reduction of section, above mentioned, by fire corrosion will take place here also, but actual experiment has shown it to be without objection, for reasons above given.

STONE ARCHES.

Of stone bridges there are some fine ones in the State, particularly on the Lake Shore & Michigan Southern Rail-

way, the Baltimore & Ohio, and the Cleveland, Columbus, Cincinnati & Indianapolis. The former has four or five large stone-arch bridges, two or three of which are two span, and they run from 40 to 80 feet diameter. Also one beautiful two-span skew arch of about twenty feet diameter. At Bellaire, the Baltimore and Ohio Railway has a remarkably fine stone viaduct, consisting of thirty-seven semicircular arches of 28 feet diameter, supported on piers 6×12 feet. The height of the copings above the streets of Bellaire is 32 feet. Twenty of these arches are in a straight line, and seventeen on a four-degree curve, all in dressed stone.

STONE QUARRIES.

In the selection of stone from Ohio quarries for important structures, care is needed lest a soft stone be taken which will not stand the weather.

THE ROADWAY.

Ordinary railroad lines consist of four parts, viz., *bed, ballast, ties and rails*. A

cross section of the most perfect roadway found in Ohio is given in Fig. 2. The Pittsburgh, Fort Wayne & Chicago Railway has some seventy miles of it, so fine in its outlines as to be truly a work of art. It is, indeed, unfortunate, that all passengers

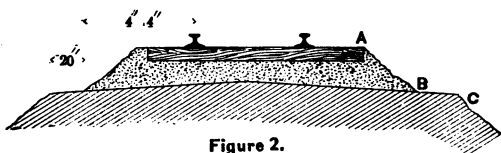


Figure 2.

cannot conveniently see it from the moving car. Observed from the rear car of a train, it appears like a beautiful striped ribbon stretching away in the distance. Across the top the stone ballast is just to the upper surface of the ties. At A a definite line of intersection is formed. At B is another, and also at C. The slope, AB, is as perfect as though the ballast had been piled under a board. The limit of ballast at B is by a single row of ballast stone between egg and nut

size, and individually laid by hand. The upper surface of the bed is crowned or convex, as shown in the figure. The part, BC, is all patted smooth with shovels. A weed is not allowed. The ballast is broken stone where this form of bed is found. The road, however, has not all stone ballast, though the amount is increasing from year to year.

Other roads have considerable portions laid with stone ballast, that ballast being much sought after. Cinder or slag from furnaces is also employed, it being preferred to some kinds of stone.

Some Ohio Stone is entirely unfit for stone ballast, and does not pay for hauling it from positions of convenient proximity. It pulverizes in use. Limestone is said to be the preferable stone. In considering what material shall be declared the best ballast, it appears that a best ideal ballast must be heavy enough to not be easily disturbed when laid, and to hold the ties in ballast ; it should not be too fine nor too coarse, say about egg size ; it should have sharp angular cor-

ners to hold the ties, and it should be impervious to water, so as to dry out quickly for preservation of ties. Probably the best possible material for uniting all these conditions is broken glass. It weighs about the same as limestone. Glassy furnace slag comes very near to it. Sandstone is the poorest of all stone, since it wears rapidly so as not to hold the ties, and it absorbs moisture, and holds it to the rapid decay of the ties. But impervious stone allows rainwater to run directly through the ballast to the bed by trickling down the surface of the fragments and without absorption. On reaching the bed it flows off to the right and left, if the bed is sufficiently crowned at its summit. In the best practice it is actually crowned for this purpose.

The minimum depth of ballast shown in Fig. 2 is six to eight inches under the ties. It often actually exceeds this, sometimes to the depth of several feet. Two reasons are given for this, first, a new bed settles causing inequalities of grade; and, second, inequalities of grade

admitted in new roads are, to a considerable extent, equalized according to growing importance of road. In these cases, rather than add new bed material to revive settling annoyances, ballast is piled on.

TIES.

Ties used in the State are mostly oak; the best being obtained from Virginia, and known as "Virginia ties." They are of white oak and run from 10" to 12" width. Chemically treated ties of elm and some other woods have been used to some extent. The number per mile varies between 2500 and 2800.

SLIP SIDES.

In a few instances "slip sides" have been encountered in which the whole fill, or embankment for a length of one or two hundred feet, will gradually be carried laterally out of place. These are found very difficult to manage. In one case, on the Baltimore and Ohio Railway, a filling of coal slack

was used after several editions of earth filling had been carried away. The coal stood very well, its less specific gravity being supposed to be the cause. In some cases piles are driven, the idea being to "pin" the slipping bank to place. But these pins often get badly demoralized from the great pressure. Springs of water are usually found along the upper limits of these slipping sides.

THE TRACK LINE.

The alignment of the track on curves often gets deranged to a surprising extent; in one case over forty per cent. by measurement was the degree of curvature raised. One instance, on the New York, Pennsylvania & Ohio Railway was noted where a curve carried the train badly. Several unsuccessful attempts were made to correct it by throwing the track by eye. Finally the curve was re-run with instruments and found badly out. In many cases the track has been observed

to be appreciably deranged where measurements were not taken.

Such derangement occurs by the working of section men on the road, as in re-adjusting grade, or outer rail elevation; in placing new ties, rails, etc. Tangent points undoubtedly "creep" from this cause, the presence of them a few feet in upon bridges, as noticed in a few instances, being apparently due to it.

Track men should have some easy and simple means of ascertaining the deformity of curves and the proper "elevation of the outer rail." For the latter an extraordinarily simple and efficient device was found in force on several roads, viz.: a cord or tape line of certain length, say 60 feet, and a rod; the former being stretched as a chord to the curve, the versed sine, measured on the rod, is the elevation of outer rail. Some use 63 feet, and others less for the chord length. For the 63 feet the elevation is right for about a 36-mile speed.

In this device we find the suggestion for a curve corrector, viz.: at all points of

an ordinary circle curve the versed-sine, for the 63-feet chord, should be of constant value.

In regard to the tangency of straight and curved portions of track, the usual practice is to make the curves true circle arcs, and exactly tangent to the straight parts. A little consideration, however, will show that instead of this, the path described by the center of gravity of a car should preferably have its corresponding parts thus in true tangency. But this cannot be where the outer rail is elevated or inner one depressed, or both, because in tilting the car for this difference of rail elevation the center of gravity is thrown in, and passes around the curve on a circle arc several inches within the circle which is truly tangent to the straight parts of the path. This has the effect to give a jolt to the car on entering on a curve. But, in practice, this is compensated in a measure by commencing the elevation of rail on the tangent itself at some distance from the tangent point, and bringing it up to the full value at or near the tangent point.

The object of making a difference of rail elevation on curves is to make the resultant of gravity and of centrifugal force take a position which shall be normal to the floor of the car. To secure this result perfectly, in every respect, it is evident that we can neither begin the elevation on the tangent nor admit of anything less than full value on the initial part of the circular curve. Neither should there be any offset, sudden or gradual, in the path described by the center of gravity of the car, such as above mentioned as due to rail elevation. Abrupt disturbances in the direction of this resultant would be perceived as jolts toward one side or the other. It is evident that the direction of a disturbance which would be least noticeable to a passenger, or have the least tendency to derail a train, would be vertical, and hence this is the most admissible. But it appears impossible to preserve quietude in every respect in a car, even though the resultant force above named could be maintained truly in the normal position

indicated, because the car must be rotated on some longitudinal axis to the extent of the difference of rail elevation. This necessitates an elevation of one side of the car, depression of the other, or a compromise action, the latter being probably preferable. Hence one rail must be depressed as well as the other elevated, the best condition being obtained when the center of gravity of the car is neither raised nor lowered.

Under these conditions, viz.: first, maintenance of perfectly normal resultant; and, second, a slight rotative movement of the car on its longitudinal axis, we secure the least possible disturbance. Then the only sensation to a passenger, if indeed any be possible in going round a curve at the proper speed, would be that of slight lifting or lowering, as depending on sitting at the lifted or lowered side of the car.

But it is clearly not possible to realize these conditions when a straight track is, according to custom, changed abruptly to a circle. Not even though the circular

curve and tangent belong to the center of gravity of the car, instead of the middle line of track. The only way to fulfill the conditions indicated appears to be, to gradually increase the curvature from the tangent to the circle by an intermediate curve of varying curvature. This we will term an *easement** curve; the main circular curve beyond the easement curve being called the principal curve.

Now the easement curve must, throughout its length, maintain perfect continuity of proper relation of the radius of curvature and rail elevation. That is to say, to meet the above conditions, the radius of the easement curve must change from point to point; and the rail elevation at any one point must be precisely that required for the radius at that point. This relation of elevation and radius is well known, viz: the elevation is simply in the inverse ratio of the

* Called curves of "*easing changes of curvature*," and "*curves of adjustment*," by Rankine; also "*spiral curves*," by others. See *Rankine's Civ. Eng.*, p. 651; *Railroad Gazette*, Dec. 3d, 1880; recent articles in *The Engineering News*, etc.

radius. Or, again, the product of the elevation and radius of curvature is a constant for any given number of miles per hour for speed of train. This is true whatever the form of easement curve, and hence the latter is neither determined nor influenced by that relation.

Being free to assume the law of the easement curve, it appears that the very best conditions possible to adopt for fixing it are to assume, first, that the car, in tilting to the difference of rail elevation as it passes along the easement curve, shall rotate about a longitudinal axis passing through the center of gravity of its cross section, and, second, that it be accelerated in that tilting movement, so that a passenger at the side of the car shall experience only the sensation of a slight change in his own weight while on the easement curve. That change of weight will be an increase if outside and going from the tangent, and *vice versa*. This change of weight, however, should be made imper-

ceptible, and it is believed so to be when arranged as below.

This makes the law relating to the time and rail elevation identical with that of falling bodies, or with

$$h = \frac{1}{2}ft^2$$

where h is the elevation, f the constant acceleration, and t the time. Now suppose that in running this easement curve, 50 feet chords are adopted $=c$.

Let the number of chords reckoned from the tangent point $=n$. Also assume that at 400 feet from the tangent point the elevation of one rail over the other be 12.8 inches. Let the number of chords passed per second by a passing train be $t=nc$. Substituting these values and reducing for a velocity of 30 miles per hour, we obtain

$$h = 0.2n^2$$

From this we obtain for

$n =$	1	2	3	4	5	6	7	8
$h =$.2"	.8"	1.8"	3.2"	5.0"	7.2"	9.8"	12.8"
$R =$	17190	4297	1910	1074	688	478	361	286

n being the number of 50 feet chord lengths from the tangent point, R the radius of curvature, and h the difference of rail elevation in inches, for a track gauge of $4' 8\frac{1}{2}''$.

For a speed of 40 miles per hour, for the same radii, R :

$n=$	1	2	3	4	5	6	7	8
$h=$.36	1.4	3.2	5.7	9.0	12.8	17.4	22.8

It is observed that the radii are the same for all cases. This makes the easement curve the same curve for all speeds, the allowance for different speeds being made in the elevation. Hence the curve can be laid out from the same set of deflection angles, computed once for all.

In a particular case of practice, the easement curve is to be continued to where the radius equals that of the *principal*, or main circular curve; when the latter is to be run tangent to it in continuation.

Now these curves should be understood as forming the proper path for the center of gravity of the car, and not

the center line of the track. For greater convenience to passengers, however, it should be the path to the center of gravity of the load of passengers. But as these centers do not differ much in position, they may be assumed coincident.

Assuming this center of gravity to be at a height above the track equal to the gauge of track, viz., $4' 8\frac{1}{2}''$ usually, it appears that in order to make the path of that center of gravity describe the easement and principal curves above laid down, it will be necessary that the curves, when first laid out on the ground, must be moved outward at each point a distance which just equals the difference in rail elevation, h , at that point. This is to provide against displacing the center of gravity as the car tilts to the difference of rail elevation.

Hence, in practice, run the easement curve as above, till its curvature equals that of the principal curve. Then set out each point the amount h proper to it as rail elevation. Then continue on the

principal curve. In laying the track depress the inner rail, the same amount that the outer one is elevated, both together being $\frac{1}{2}$. This is to be done for that speed of trains at which it is desirable to have the most perfect freedom from all manner of disturbances.

In compound curves not reversed, the easement curve should be introduced to give a gradual change of curvature, rail elevation, &c., from one curve to the other. In reversed compound curves, the easement curve and elevations should be used to change from the first principal curve to where the track would run off on a straight tangent, and then it is to be run, in the inverse order, to where its curvature equals that of the second principal curve, &c. In short, every portion of principal circular curve should begin and end in an easement curve, as described above.

This gives perfect freedom from side jolts and a probably imperceptible vertical lift or decadence. To give an idea of the latter effect, that is to say, of the

apparent gain or loss of weight, suppose a man of 200 pounds weight to be at the extreme side of a car, and that the car enters upon the above easement curve at 30 miles per hour. The accelerative lifting or depressing force due to the 200 pounds weight will be, by calculation, only 0.16 of a pound, or about $2\frac{1}{2}$ ounces, an effect which would influence the cushion of the car seat less than to place an orange in the rider's lap.

But all the above refinements respecting the alignment in the horizontal plane will be of but little avail where the importance of the vertical alignment is ignored. From an extended examination of track, both by sightings from the ground, and by taking advantage of opportunities of riding miles within one or two hundred feet of a second track, and of allowing the two lines of rail to spin through a fixed gaze with a view to observing the relative heights of the two rail lines, it is believed that the error of vertical alignment is usually at least five-fold greater than in the horizontal.

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Of two sections of road, if one should be found as badly out in the horizontal alignment as the other in the vertical, each otherwise correct, it is altogether probable that the section boss of the former would get his discharge the first time the road master came along, while the other would very likely be commended. But in this case the wrong man is discharged, because, as to the riding qualities of the two sections of track, the former would be far the best. This fact is evident by observing that the weight of the car is sure to cause it to follow all inequalities in the vertical alignment, while most of the lateral deviations of the rail will be skipped, and pass without effect. But even if followed to detail, in both instances, the vertical deviations will rock and tilt the car badly, and cause disturbances which will be magnified by the height of passengers or freight above the track. To explain, suppose one rail perfect in line, and the other to rise and fall one inch, in distance of fifty or a hundred feet. Here

one wheel has a latitude of vertical movement of one inch. The straight rail forms an axis to this motion, and if a circular cylinder, of radius equal the track gauge, be drawn to this axis, cutting the car lengthwise, every point in that cylinder would have the one inch of motion. That is, a point vertically over the straight rail, at the height of track gauge, would move sidewise one inch when the wheel on the opposite rail rises and falls one inch. Persons in seats directly over the straight rail receive the lateral jolts of about one inch. But persons in the seats at the opposite side of car receive jolts which are both vertical and lateral to the extent of about one inch, which amounts to a diagonal jolt of about one and a half inches. The top of the car may, at the same time, be thrown two or three inches. (See Appendix.)

This supposes one rail straight, but it is as likely to be cut as the other; both sometimes together and sometimes opposite. In case both rise together one

inch, the car receives the vertical displacement bodily of one inch.

But when they are in discord, the passengers are thrown to an extent nearly double that due to the single rail error above. The consequent jolting annoyance cannot safely be prevented by rigid car-couplings, because the strains would be great upon the couplings; and no coupling attempts it.

But now suppose equal inequalities in the lateral direction or in the horizontal alignment. The wheels would skip most of them, the tendency being to go nearly straight ahead rather than turn out for all side-crooks in the rails. This is rendered possible by the clearance between the wheel flanges and rails. The cars are prevented, to a great extent, from wandering from side to side of the clearance by use of couplings, which offer a considerable resistance to the lateral movement of one car end, crosswise to the one coupled to it.

From these facts it appears that the vertical alignment is the one which de-

mands the most careful attention for exactitude, while in practice it seems to receive the least.

"Low joints" are found everywhere, though in the most carefully guarded track they are slight. Where the "fish plates" are allowed to get loosened, the wheel pressure and peneing action bend the rails to an arched form. Small "joint ties" also favor low joints.

If the rail joint could be given the same stiffness as the body of the rail, and then if the bearing of the ties upon the ballast could be uniform along the rail line, the rails would remain straight. The "angle bar" is superior to the fish plate for making a stiff joint; but as no joint in use is as strong as the body of the rail, it follows that the deficiency should be made up by a greater amount of tie bearing near the joint. There are many advantages in the so-called "suspension joint." It is formed by placing the abutting ends of the rails over a space of about ten or twelve inches between two ties, so that the fish plate or

angle bar will span the space, and be secured upon the ties. The advantage of this in the matter of low joints consists in the greater amount of tie bearing upon the ballast at the locality of the joint, and due to the fact that these two ties are nearer each other than other ties along the rail. But still the tendency is to low joints, and it seems necessary that, in laying ties, the two widest ones be selected for the pair at the suspension joints. This, together with closely-fitting angle-bars, it is believed will maintain freedom from low joints. This is based upon the supposition that the ties along the middle portion of the rail be all smaller than the joint ties.

But, in actual practice the joints in one line of rails are sometimes placed opposite those in the other line, and sometimes the joints alternate. Some road masters strenuously insist on opposite joints, others equally so on alternate, and each will have no other. This is the one thing about railroads on which there

is found the greatest prevailing difference of fixed opinion.

Now, respecting the bearing of the joint ties upon the ballast, 1st, when the joints are opposite, we find that the selected wide ties, which become joint ties for one rail line, are also in proper position to serve as joint ties for the other line. This also leaves the middle portions of the rails resting on the smaller ties, a condition pointed out above, as favorable for preventing low joints. But when the joints are alternate, the wide ties selected must be twice as numerous, and consequently differing less from the remaining ones ; but besides this we find that the wide ties for the joint at one side extend across, and become wide ties at the middle of the opposite rails. This favors low joints, as pointed out above, and is one reason why alternate joints should be avoided.

But some contend that alternate joints ride more easily and pleasantly than opposite. This is probably true for equal degrees of low joints. but it seems to be

an open question whether the alternate joints, with their greater tendency to low joints, will carry trains more smoothly than will opposite joints well laid on the selected joint ties. But on some roads very little if any attention is paid to selecting joint ties. In such case it is probable that alternate joints will ride smoothest.

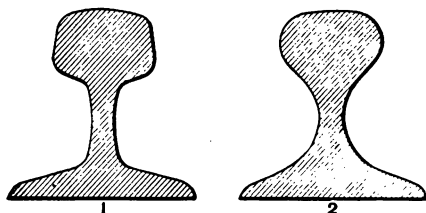
It might be supposed that alternating low joints would give an oscillating motion of car from side to side, and opposite joints a vertical oscillation. The latter is likely to occur for speeds under about twenty-five miles per hour. But in high speeds the time between joints is too small for serving as a period of vibration or oscillation. Hence it cannot take place. At thirty miles per hour, alternate low joints appear to be entirely without effect for all oscillation, and is not noticed at even twenty or perhaps fifteen miles per hour.

From these facts it appears that low joints can be more effectually avoided when opposite, but will have less prejudicial riding qualities when alternate.

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RAIL SECTIONS AND WEIGHTS.

The form of rail section is a matter of considerable import. The prevailing modern form is nearly like No. 1, Fig. 2*a*, while some of the older rails in use in the State are nearly like No. 2. Various devices have been used for making the

Fig. 2 *a*

joint in No. 2, but it is a hard rail to hold. Fish plates and bolts soon release their grip. The bolts are apt to break, but they first stretch and loosen the plates. Then the plates, rails, and bolts wear badly, because the form of section is seen to not be favorable for holding a fish plate. On the other hand, the upper and lower parts appear much as

though they would serve admirably as wedges to spread the fish plates and tear the bolts. In some cases wood is used on one side, and sometimes both wood and iron.

But the nearly square shoulders between the head and foot in No. 1, are seen to be especially well adapted to hold a fish plate. Even a little looseness under the fish-plate bolts would not admit of very much vertical displacement of one rail on the other at the abutting ends.

Rail weights vary on Ohio roads from 50 to 67 pounds per yard, the most common being 60. It is often the case that heavier rails are laid on curves than on tangents. This is to provide against the greater wear on curves.

LOCK NUTS.

In spite of the fact of numerous existing lock nuts of merit, none seem to meet all the requirements for fish-plate bolts. The simplest found in use is the Verona lock nut. It consists of a

split and offset ring of steel, tempered to a spring, and having cutting points at the split. It appears to be made of quarter-inch square steel, cut and bent nearly to a ring, but having an offset of about one-eighth inch, where the ends nearly meet to form the ring shape.

WEAR OF RAILS.

Practice develops the fact that the outside rail on curves becomes by far the most worn. In some cases the outside worn rails, and inside nearly perfect ones, are interchanged, so that each shall get its portion of wear. The wear now referred to is mostly on the side of the rail head. The tops of the heads also become much worn. Altogether the wear on curves is much in excess of that on tangents, a fact which accounts for laying heavier rails on curves.

The fine theory of the "coning of wheels" is entirely without force in practice. Wheels wear most near the flanges, so that in a short time the effective con-

ing is reversed; that is, the wheels become smaller in diameter of tread at points near the flange than at points remote from it. It seems evident that the more wheels become thus worn and lose their coning, the greater will be their tendency to climb outward on curves, and consequently the greater will be their slip and the greater the wear, not only of wheels, but also of the rails on curves.

The recent improvement in chilled car wheels of leaving an inch at the rim-edge of tread, without chill, will doubtless tend to make the wear more uniform over the whole tread.

SWITCHES AND FROGS.

A great variety of notions about switches and frogs are found in vogue. For instance, some have decided preferences for the Lorenz switch, and others for the Wharton, where any other than the ordinary plain switch is desired.

The Wharton switch is the homeliest switch, probably, that was ever made. It

would never get adopted from any good looks. But it has great advantages for certain positions in track. A remarkable property of it consists in its leaving the main line of track entirely intact or unbroken. This is secured by means of parts so formed and raised as to lift the wheels high enough to carry the flanges over the rails at the one side. In practice, both sides are raised. This raises the cars also in passing the switch, a requirement which could not be admitted at high speeds of train.

Hence it appears that this switch is especially adapted to places where trains are to pass at high speed along the main line, but where it is necessary to occasionally turn out to a side track, the latter being always at a reduced speed. Being a "safety" switch, it is well adapted for yards and all places of much switching at slow speeds. While the Wharton switch requires one sharpened rail, the Lorenz requires two. These are so fitted that they will lie close up to a whole rail, and receive a wheel from it.

The Lorenz admits of two unbroken lines of rail, but one of them turns off to the branch track, so that one rail of the main line is cut. In this rail it becomes unnecessary to raise the cars in switching. Hence this switch is adapted to location where a train may continue on main line or take a branch at speed. This switch is made a safety switch by introducing a spring. But the spring is seriously objected to by some, with the statement that a stick or pebble may become engaged between the pointed and fixed rail, and thus throw a train. Devices have been introduced for obviating this objection.

Beside the ordinary "frog," two others are found in use, viz.: the spring frog, and the self-acting frog. Some roads are very partial to one or the other of the two latter, while others will have nothing to do with them. The chief objection seems to be that the movements are apt to become obstructed by sticks, dirt, cinder, snow or freezing, &c. But on main lines, where turnouts are to be passed at speed, and on lines passing fifty to

a hundred trains per day, a common frog is apt to become much worn in a comparatively short time. The spring and the self-acting frogs have far greater wearing qualities than the common frog, because they secure nearly the effect of an unbroken rail. Where switching is not frequent, and trains pass at speed, the Wharton switch and spring frog are good accompaniments.

BRIDGES ON NEW ROADS.

Economy in the management of railway structures favors the adoption of cheap wooden ones, such as trestles, pile bridges, &c., in the construction of roads, the same to be renewed in due time by more permanent ones. One important consideration in regard to this is the practical "water-way" under bridges. In some cases trestles, a few hundred feet in length, have been introduced at points of unknown water way, which have subsequently been reduced to a complete fill, with the exception of a tile opening. In other cases iron structures have been un-

dermined by reason of a cramped water way.

The life of a wooden bridge is, perhaps, none too long for enabling the engineer to learn the actual demand upon any bridge location for the water way. In one instance, a fine Pratt truss of over one hundred-feet span was placed over a nearly dry channel, at a height above bed of only about five feet. A stranger to the locality would wonder why the space was not filled with dirt, at a cost of almost nothing comparatively. But should he happen to be along at the one or two times a year when water was up, he would form an opinion, sound and correct, as to water way.

CATTLE GUARDS.

This structure, though of seeming insignificance, is yet of very great practical moment. This is due to two facts, viz.: first, the great number of them required on a single road; and, second, that any one defective cattle guard is sufficient to wreck a train.

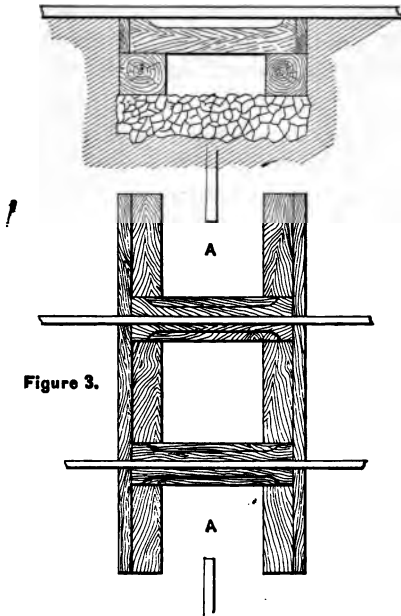
The amount of attention given to this matter by different roads varies greatly. For instance, they have been found built, except the "strings," of ordinary rail ties, and without much designing either. Some roads have an almost infinite variety, and most of them being built of such material and in such manner as is most convenient to the locality. Others will not only have a carefully designed and specified "standard cattle guard," for universal use, but will have material lying in their material yards all along the road, cut to specifications and ready for setting new guards, or for repair of old ones, on the plan of interchangeable parts.

The latter system reduces the matter of cattle guards to a basis of manufacture, with all its advantages of economy, stock on hand, &c.

The three most characteristic standard cattle guards, observed by the writer in the tours of inspection, are here described.

The standard of the Pittsburgh, Fort

Wayne & Chicago Railway, shown in Fig. 3. A pit is first sunk nearly three feet



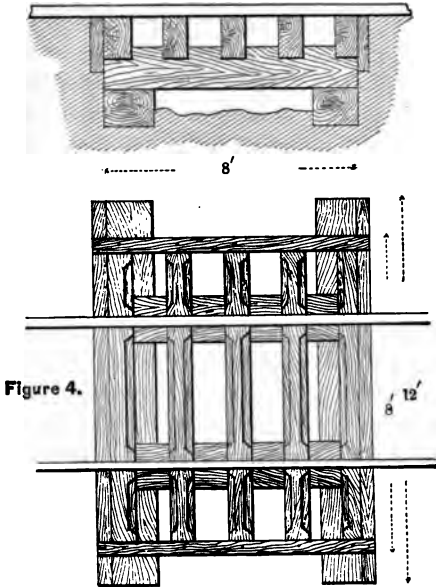
deep, filled nearly one foot with broken stone. Then two square timbers, about

12'' \times 12'' \times 12' are laid crosswise the track at each side of the pit, and resting on the stone. On these, against the pit's banks, are laid, on edge, planks about 3'' \times 12'' \times 12'. Between these planks the "strings," about 12'' \times 12'' \times 6 or 8', are placed one under each rail, as shown. The planks are heavily spiked to the strings, thus fixing the distance between the latter. The rails are spiked directly to these strings, the latter being chamfered. The fence, on either side, terminates about at A, as shown. An effort is always made to drain the pit by a channel, so that water scarcely ever lies about the pit timbers or mudsills.

In this guard the pit is generally left open, and is about two feet deep. Slats are sometimes put on, though this seems to be the exception.

The standard of the Cleveland, Tuscarawas Valley & Wheeling Railway is shown in Fig. 4. Two sticks, about 12'' \times 12'' \times 12' are placed in the bottom of the pit. 8', out to out, crossing the rail line. On these are placed two sticks or

strings, about $12'' \times 12'' \times 8'$, one under each rail. On these last are placed 5



sawed ties $6'' \times 7''$ or $8'' \times 8''$ and notched on to a remaining depth of $6''$. The

outer ties are placed flush with the ends of the sticks on which they are notched. Against the outsides of the outer ties, and extending down by, partly over the ends of the strings, are placed planks about $3'' \times 12'' \times 12'$ and spiked. Across the ends of the ties a binder or guard rail of wood is bolted. The rails are spiked upon these ties as on any other ties. The upper corners of the ties are chamfered.

This is believed to be a most efficient guard. Its cost, as compared with that of Fig. 3, depends mainly on whether the five sawed and chamfered ties, and guard rails and bolts, of Fig. 4, cost more or less than the stone filling in the bottom of Fig. 3.

The Baltimore and Ohio Railway have a more elaborate and costly standard, shown in Fig. 5. In the bottom of a pit three mudsills are placed, each about $12'' \times 12'' \times 12'$. Across and on these are laid the string pieces, one under each rail, and $12'' \times 12'' \times 8'$. The ends of these are notched into $5'' \times 12'' \times 12'$

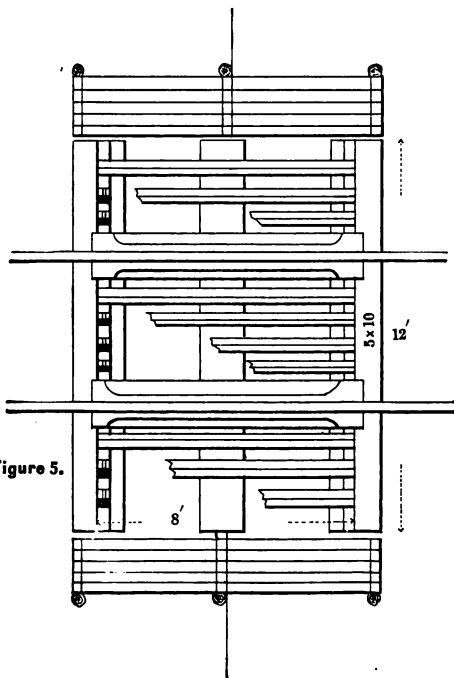
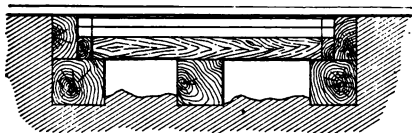


Figure 5.

planks, the outsides of the latter coming just flush with the two outside mudsills. The strings are chamfered, and the rails are spiked to them.

Slats or bars are counted an essential part of their guard, and they are provided for in a most ingenious manner. On the inside of each of the outer heavy $5'' \times 12''$ planks is spiked a $1\frac{1}{2}'' \times 8'' \times 12'$ plank, notched at spaces of about 12''. The notches are diagonal, so as to carry $4'' \times 4''$ bars lying in a diagonal position, that is, so that one corner of each stick is up. These bars are not nailed, because in a few months they sag, and are then turned over. As often as any one sags it is reversed.

At each side of the track, or end of the guard, is placed a half length of fence as shown, from which starts out the division fence to which the cattle guard belongs.

Nothing would seem to be more efficient than this as a cattle guard, and yet the road master states that in one case a certain man's cow had educated herself

to such a point of excellence that she would deliberately and safely walk the champered stringers, placing right feet one side and left feet the other side of the rail. But this isolated instance of successful climbing cannot be considered due to any fault of the cattle guard. •

GRADE.

The steepest grade noted by the writer is 85 feet to the mile, though that is very likely exceeded in the State. Very little attention appears to have been given to controlling grade; or least possible maximum grade per division, or other portion of road. Neither to the matter of grade compensation for curvature. These questions appear to rise to great importance only on long stretches of road through uninhabited country like our western wastes, where it is not convenient to locate "helper engines" for an occasional excessive grade.

But in Ohio, a road master will reply, stating the steepest grade, and give its location; and also that it is perhaps ten

feet or fifteen feet steeper than any other. He may say, also, that in each case the grade was made as small as possible, regardless of reduction of cost of road by allowing the grade to go up to the controlling maximum at any point on a portion to which this controlling maximum belongs.

SUPPLEMENTAL.

CURVES AND CROSSINGS

FOR

RAILWAYS.



Curves and Crossings for Railways.

I. FORMULAS AND TABLES FOR EASEMENT CURVES AS ADAPTED TO FIELD PRACTICE.

SINCE the above on Railway Economics was written the problem of the "easement" curve has been pursued farther with a view to putting results and facts in the most convenient shape possible for use by field engineers.

It might at first be imagined that the complexity of practice with any easement curve must necessarily be so great as to render its use entirely out of the question. But a little consideration of the table of quantities given below will show that this is not the case; indeed, from the fact that the quantities needed are already made out and given in tabular form, it may be found easier to construct easement curves than circular curves. Though a great variety of easement

curves is possible, only one is necessary, and when this one is selected, all the quantities pertaining to it which are needed in practice can be at once computed and tabulated, the table being extended to include any case of practice. This is seen to be possible from the fact that any proper easement curve must be a sort of a spiral, beginning with an infinite radius at the point of departure from the straight tangent, and extending to where the radius of curvature becomes equal to that of the principal circular curve to be joined with it. Hence the table should be carried to the smallest admissible radius of principal circular curve; which table representing some one carefully-selected spiral or easement curve, is ready for every case, and furnishes deflection angles already made out for part of every curve to be run in practice. Indeed it is possible by aid of the table to run in a complete railway curve between any two tangents, consisting wholly of two portions of the easement curve in common tangency,

and without computing a single deflection angle, nor summing them for total deflections.

On the other hand it is well known that some species of easement curve is absolutely necessary for the transfer of a train from a tangent to a circle curve without the disturbance of the lateral equilibrium. Hence easement curves are a necessity to perfect track.

A number of curves have been proposed for effecting this easing, and a few of them have been used in practice. But probably no rules for practice heretofore published came nearer to realizing the needs of practice than those presented in a most excellent article in the *Railroad Gazette* of Dec. 3, '80, by Ellis Holbrook, C.E., of Richmond, Ind. A table is there given which contains most of the quantities required. Mr. Holbrook is introducing these curves on the Pan Handle Railroad.

The methods of that article are found of such rare merit that they are followed largely in this, the chief difference being

in additions which aim to more fully anticipate the needs of practice. A different curve is, however, adopted in the present instance for reasons soon to be given.

The curve of Mr. Holbrook is a spiral with infinite radius at the tangent point, and with the radius of curvature varying inversely as the distance from the tangent point as measured along the track.

From the general considerations offered in the principal article above, under "The Track Line," it appears that the spiral there adopted is one in which the radius of curvature varies inversely as the *square* of the distance from the point of tangency. The object in choosing the square was to reduce disturbances, due to entering upon the curve, to the least possible value, as fully discussed in the principal article. For the same reason the law of the square is still retained.

The elevation of outer rail on curves is well known to be inversely as the radius of curvature of the track curve. Hence in the present case the elevation va-

ries directly as the square of the distance from the point of tangency. By choosing the law of the square, the acceleration of the car in its rotation on a longitudinal axis as already explained is made constant, and to a person sitting at the extreme side of a car, the only sensation due to entering upon a curve would be that of a slight increase of weight, or of decrease, as the case might be; and which would continue constant throughout the easement curve. But where the variation of elevation and of consequent rotation of car on a longitudinal axis is as the first power of the distance from the tangent point of the curve, the elevation of a person at the extreme outside of the car would be uniform as the car rotates, but that uniform rate would have a sudden beginning at the initial point of the curve; the action being like that of imparting a uniform motion upward to a body from a state of rest by an instantaneous knock. Though the practical effect of this instantaneous impulse may be declared insignificant; yet from

a circle curve shown by dotted lines might be put in from a center O.

Let A and B be the tangent points for the new curve in which AG and BJ are the equal easement curves, and GJ the principal, or intermediate circle curve. Perpendiculars at A and B meet in O, at an angle equal the angle of intersection of the tangents. The circle may be extended back from G to F where its tangent is parallel to AC. O is taken a common center to the dotted circle DH, and the principal circle GJ.

In running the curve in the field, we may start at the point A. With chords and tabulated deflection angles, run to G; then set the instrument at G and run the circle GJ; then go to B and run the easement curve BJ. To eliminate inaccuracies it may be advisable to run the two easement curves first. Then with the instrument at G examine the total deflection angle for J. If the discrepancy is small, set on J to dispose of it, and connect G and J.

To conveniently express relations between quantities, take

I = the intersection angle at $C = DOH = AO_1B$. Then $DOC = \frac{1}{2}I$.

R = the radius OD to the ordinary circle curve dotted in.

R_1 = the radius OG, OE, OJ to the principal curve.

$R - R_1 = DF$ = the normal distance between the circle curves named.

T = the tangent DC to the circle to radius R .

T_1 = the tangent AC to the new curve.

$T_1 - T = AD$ = difference of the two tangents.

i_1 = the angle between the tangent line to the easement curve at G , and the tangent T . $i_1 = GOF$.

D_{Δ} = total deflection angles laid off at A , from the tangent AC for running the easement curve. The greatest one for a particular curve is GAC .

D_t = total deflection angles at some point on the easement curve, from a line parallel to AC , to points beyond.

$D_{l=200}$ = total deflection angles for the instrument at 200 feet from A as measured along the easement curve.

l = length of the easement curve counting from A.

x_1 and y_1 = co-ordinates to the point G, as shown, but given for every 10 feet of the curve l .

From the fact that the easement curve AG is a certain definite spiral curve of increasing curvature, it is evident that it will fit all circle curves, GJ, of whatever radius; because, beginning with an infinite radius, it is only necessary to run it to where its radius equals that of the principal curve GJ, whatever that may be. Hence the various quantities pertaining to the easement may be calculated once for all for every point and tabulated. To do this we require equations, such for instance as are given below.

According to considerations already presented, we have, for a constant train speed,

$$h = \frac{\text{const}}{\rho}$$

where h is the difference of elevation of the two rails, and ρ the radius of curvature of the spiral at any point. Also,

$$h = \text{const. } t^2 = \text{const. } n^2 = \text{const. } l^2 = \frac{\text{const}}{\rho}$$

Take the constants such that

$$h = al^2$$

and
$$\rho h = \frac{a}{3b}$$

Then
$$\frac{1}{\rho} = 3bl^2$$

These are the fundamental relations.

Now at any point on the spiral easement curve the radius of curvature ρ is perpendicular to a tangent drawn to the same point of the curve; the latter, as above explained, making the angle i with the principal tangent T. Hence for a small variation of the position of the point considered, along the curve l by an infinitesimal dl , the radius ρ will swing

through an infinitesimal angle di .
Hence we have the relation

$$\rho di = dl,$$

or by introducing the value of ρ

$$di = 3bl^2 dl$$

Integrating this for limits reckoned from zero, we have

$$i = bl^3$$

Also by the figure it is easily seen that

$$\frac{dy}{dl} = \cos i = \cos bl^3,$$

$$\frac{dx}{dl} = \sin i = \sin bl^3$$

Expanding the sine and cosine into series, we have

$$\frac{dy}{dl} = 1 - \frac{(bl^3)^2}{1.2} + \frac{(bl^3)^4}{1.2.3.4} - \&c.,$$

$$\frac{dx}{dl} = bl^3 - \frac{(bl^3)^3}{1.2.3} + \frac{(bl^3)^5}{1.2.3.4.5} - \&c.,$$

which, for limits reckoned from zero become

$$y = l \left(1 - \frac{(bl^2)^2}{1.2.7} + \frac{(bl^2)^4}{1.2.3.4.13} - \&c. \right)$$

$$x = bl^4 \left(\frac{1}{4} - \frac{(bl^2)^2}{1.2.3.10} + \frac{(bl^2)^4}{1.2.3.4.5.16} - \&c. \right)$$

From these equations, the co-ordinates to the spiral curve can be computed.

If we apply the subscript 1, to a particular set of quantities belonging to the point G in the figure, we may write

$$R_1 = \rho_1 = \frac{1}{3bl_1^2};$$

$$R - R_1 = x_1 - R_1(1 - \cos i_1),$$

$$= x_1 - \frac{1 - \cos i_1}{3bl_1^2}.$$

$$= x_1 - \frac{bl^4}{6} \left(1 - \frac{(bl^2)^2}{1.2} + \&c. \right);$$

$$T_1 - T = y_1 - R_1 \sin i_1$$

$$= y_1 - \frac{\sin i_1}{3bl_1^2}$$

$$= y_1 - \frac{l_1}{3} + \frac{l(bl^2)^2}{18} \left(1 - \frac{(bl^2)^2}{20} + \frac{(bl^2)^4}{873\frac{1}{8}} - \&c. \right)$$

For total deflection angles at A we have

$$\tan D_A = \frac{x}{y}$$

when x and y are co-ordinates to the point to be located by the angle D_A .

For deflection angles laid off at any point $x' y'$ on the curve, from a line parallel to the tangent T, we have

$$\tan D_l = \frac{x-x'}{y-y'}$$

which applies for points forward or back of $x' y'$. This deflection angle is useful when it is desirable to move the transit instrument from A to a point on the curve for passing obstacles, &c.

From a point on l , 200 feet from A, measured along the curve,

$$D_{l=200} = \frac{x-x_{200}}{y-y_{200}}$$

A deflection angle from the tangent T at any point y' , on that tangent for locating points xy on the curve, is given by

$$\tan D_T = \frac{x}{y-y'}$$

These deflection angles are intended for use in the ordinary way in practice, along with the chain for running the curve.

The tangent T to the dotted curve is given in terms of the radius R of that curve, and the intersection angle I , by the well known relation

$$T = R \tan \frac{1}{2} I.$$

CONSTANTS FOR PRACTICE.

For the elevation of the outer rail we have for 30 miles per hour of train speed, and for l in feet,

$$\begin{aligned} h &= al^2 = .0000793l^2 \text{ inches,} \\ &= .0000066l^2 \text{ feet.} \end{aligned}$$

For 45 miles per hour, and l in feet.

$$\begin{aligned} h &= a'l^2 = .0001785l^2 \text{ inches,} \\ &= .0000149l^2 \text{ feet.} \end{aligned}$$

The value of b which has been adopted is given by

$$\text{com. log } b = 1.8955 - 10.$$

SPECIAL CASE OF EASEMENT CURVES ONLY.

That the whole curve may consist only of two equal portions of the easement

curve tangent to each other in the middle, the points G and J must fall at E, and we must have

$$i_1 = \frac{1}{2}I$$

also radius at E = radius for $i_1 = \frac{1}{2}I$ or

$$R_1 = \frac{1}{3bl^2} = \frac{l}{3i_1} = \frac{2l}{3bI}$$

where i or I is expressed in arc to radius unity, and common log $b = 1.8955 - 10$.

The length of the entire curve is twice the length l_1 to the point where $i_1' = \frac{1}{2}I$.

PATH OF CENTER OF CAR.

It has been explained that the center of gravity of the car is the point which should describe the curve here laid down, and not the center point between the wheels. This requires that the track at the curve shall be laid outward of the line run by the instrument and chain, by an amount about equal at any point to the elevation of the outer rail; since the center of gravity of car and load is above the rails a distance about equal to the track gauge.

THE FIELD PRACTICE.

To facilitate the field operations in running easement curves, values have been computed for every 10 feet of the curve and tabulated so that the curve may be staked out directly by stakes set 10 feet apart or at multiples of 10 feet. These computed quantities are given in the accompanying table, which the engineer should have placed in his note book for convenient use in the field.

To illustrate the use of the table take the following :

EXAMPLE.

Given the intersection angle $I=60^\circ$ and the radius, R , for an ordinary circular curve=1061 feet.

Then by the usual formula and calculation for circular curves,

$$T=R \tan \frac{1}{2} I=1061. \tan 30^\circ=612.6 \text{ ft.}$$

Hence to run in a circular curve, we go 612.6 feet back on the tangent from the intersection point, and start with deflections and chaining, the total deflection having been made out.



But to introduce the easement curves we must go back from the intersection point the 612.6 feet, plus the tabular distance, $T_1 - T = 133.3$ found opposite $R = 1061$, or $612.6 + 133.3 = 745.9$ feet $= T_1$; and from this point—A, in the figure—start with the chain and the total deflection angles given in the table according to the chord length. For 10 feet chords, setting stakes 10 feet apart, use all the deflection, D_A , given in the table. For 20 feet chords use alternate ones. For 50 feet chords use the $49''$, $6' 44''$, $22' 56''$ and $54' 02''$. For any length of chord we must in this example end the easement curve at 200 feet, because by the table $\frac{l}{10} = 20$, or $l = 200$ where $R = 1061$; and hence the last total deflection on the easement curve will be $D_A = 54' 02''$.

At this point the radius of the easement curve is $R_1 = 1060$ feet; and this is the radius of the principal, or circular curve extending it. The angle between the tangent to the easement curve at this

point and the tangent T is $i_1 = 3^\circ 36' 18''$, as given by the table. Hence the instrument can readily be set up at the end of the easement curve and brought to tangency. The circle may then be run, its deflection angle being half the degree of the curve or $2^\circ 42' 12''$ as obtained from the table.

The length of the easement curve l , is 200 feet.

The angle of the principal curve will be $I - 2i_1 = 60^\circ - 7^\circ 12' 36'' = 52^\circ 47' 24''$. This divided by the degree gives the number of chords of 100 feet, and consequently the length of curve.

If both easement curves have been run before setting the instrument at G, the work may be checked by sighting on J with the total deflection for that point.

The elevation of the outer rail for the principal curve is the same throughout as for the easement curve at G, and $=.264$ feet, $=3.1''$, for a 30-mile speed. For points along the easement curve, the elevation is given in the table.

These values of the elevation are the

amounts by which to set the track outward in order to carry the center of gravity of the car on the curve as already explained. Hence the principal curve is to be laid outward about three inches, all its length. The easement curve is to be laid outward 0.2" at 50 feet; 0.8" at 100 feet; 1.8" at 150 feet, and 3.1" at 200 feet, where the circle curve begins. These are for the 30 mile speed, the offsets being found in the elevation column of the table.

II. SPEED AT GRADE CROSSINGS.

The so-called "know-nothing stop" appears to be in force everywhere at points where one track crosses another at grade. In some states this is obligatory by state law. But the practice is universal, and appears not to depend at all upon state law.

Very little thought appears to have been given to the subject of economical crossings of railroads. In some instances as much money appears to have been expended in cutting to make a crossing "*at*

grade" as would have been required to fill sufficiently to put the crossing "above grade." But in many instances thousands of dollars more better have been expended to carry one line over the other, than to have placed them at grade.

Some roads will place their estimates of expenses for all their stoppages at a single crossing point at from 100 to 500 dollars per day. We will probably be entirely safe in basing figures on the lesser amount, as true, for a great number of railroads. For 300 days to the year, the \$100 per day will pay interest at 6 per cent. on an expenditure of half a million of dollars. Hence at such a point as the one now considered, it would be economy to make an expenditure of anything less than \$500,000, to carry one line over the other. This money would cut about a mile of tunnel. A hundred such grade crossings in a state would amount, on account of stoppages, to enough to build, equip and maintain a first-class railroad across the largest state east of the Mississippi.

But more definite figures on this point may be found of interest.

The forthcoming report of the Commissioner of Railroads of Ohio contains the following figures, viz.:

Total number of grade crossings reported by all roads in the State, 252.

Total miles of railroad, 5,835½.

Average number of trains that passed over each mile of railway during the year, 5,680.

Gross earnings of all railroads in the State for the year 1881, \$33,116,271.

From these figures we find the average distance between two consecutive crossings on any one line of road to be $\frac{5,835\frac{1}{2}}{252} = 23.1$ miles. Average number of

trains over each mile in one day, counting 330 days to the year, Sunday being allowed as about a third of a day in train running, is $\frac{5,680}{330} = 17.03$. Gross

earnings per day, $\frac{\$33,116,271}{330} = \$100,352$.

Assuming the average distance run each

day by one train at 14.3 miles per hour, the time on the average required for a train to move from one crossing to the next, including all stops such as for taking and discharging local freights, taking water, stopping at crossings, &c., is $\frac{23.1}{14.3} = 1.61$ hours ; or 96.6 minutes.

Now allowing five minutes as a fair average for the time lost by a train in making the crossing stop, we find that

$\frac{5}{96.6}$, or 5.176 per cent. of the running

time is consumed in stopping at grade crossings ; time which, except for the crossing, would be used in making headway ; because steam is up and all the needed men are at their posts of duty. The 5 minutes is taken as an average for all trains, freight and passenger ; a figure which is placed considerably higher by some good judges. By avoiding this stop, it appears Ohio roads could increase their daily earnings by over 5 per cent of the actual earnings,

or exactly to the amount $\frac{\$100,352}{1-.05176} =$
 $\$105,830$; which shows a gain of $\$105,830 - \$100,352 = \$5,478$ per day for Ohio roads; a gain in earnings which it is fair to suppose would follow the abolition of the know-nothing stop.

To find the cost of a single stop, we have by multiplying the average number of trains per day by the number of crossings reported $= 17.03 \times 252 = 4292$. = the number of daily crossing stops. As these cost $\$5,478$, it appears that a single stop costs as an average $\$1.28$.

The total cost of stops for the year 1881 appears from the above figures to be $330 \times \$5,478 = 1,807,740$, or nearly two millions of dollars. This capitalized at 6 per cent., amounts to the enormous and seemingly incredible sum of over 30 millions of dollars. The actual number of crossings is evidently only half the number reported by all roads, because any one crossing gets reported by both of the roads intersecting. Hence the number of grade crossing-points in Ohio

in 1881 is 126. It appears, therefore, that there might be invested on 6 per cent. borrowed capital at each crossing

point the sum of $\frac{\$30,124,000}{126} = \$239,120$;

or nearly a quarter of a million of dollars as the amount that might be expended at each crossing point for appliances which would enable trains to pass the crossings at full speed.

In some States the law compelling the know-nothing* stop has recently been repealed. This is true of Massachusetts and Ohio,† but the repeal only followed convincing proofs that better systems for making the crossing existed. Switch and signal appliances have been so perfected of late as to place at the disposal of Railroad companies means for passing

* Called the know-nothing stop from the fact of the passage of the law compelling it in Massachusetts the year of the political "know-nothings."

† In Ohio it is virtually not a repeal, but provides an option, viz.: that railroad companies may, in preference to the stop, adopt and use means for crossing at speed which, in the opinion of the Commissioner of Railroads, is fully up, in safety, to the know-nothing stop.

grade crossings at full speed in a manner conceded by those who are familiar with it to be decidedly safer than by the old compulsory *stop*.

To realize this fact of enhanced safety it should perhaps first be noted that the compulsory stop is not absolutely safe. For instance a freight train on a down grade approach, might become unmanageable and break into a train making the crossing. A rear locomotive on a long freight train, especially when around a curve out of sight of crossing and flagman, might under certain circumstances remain under steam without knowledge of error, and push the forward end into a crossing train. Though such instances are rare, yet they are known to have occurred.

Suppose each branch of track at a crossing to be provided with a derailing switch, so that in each instance just named above, the train in error would have been derailed, or turned into a side track. This would have avoided the crash in the two instances mentioned, but

the four switches, while avoiding two accidents, might occasion ten for the extra attention they require; unless accompanied by operating mechanism far superior in control to that which has been employed in past years. But the modern greatly improved and wonderfully perfect *interlocking* switch and signal apparatus is fully competent to the task.

Indeed the modern "block system," in making a single block each way at the crossing, would in all probability be as safe for passing at speed when clear, as would be the old-fashioned stop. But the addition of the derailing, or side-track switch on each branch of track, and so worked by interlock, with the signals of the block that only one track can possibly be set clear at a time, seems to leave nothing to be desired for absolute safety; at least for a far greater measure of safety than is possible with the old know-nothing stop.

Apparatus working with the degree of precision and certainty just indicated is

already in use on some important lines of railway, a notable instance being found in the blocks by which the Pennsylvania Railroad enters the city from West Philadelphia to its magnificent new depot at Broad and Market Streets. Here all the switches for handling the 250 trains per day which are brought in and out of that depot, and the signals for governing the movements of those trains, are interlocked with each other. In one tower is a machine with 56 levers, and by it are operated all the switches and signals belonging to the track, extending from the depot back to a distance of about half a mile. By this machine all the trains can be handled at any one time by one man.

The most wonderful feature of all this maze of tracks, switches, signals, and operating rods, cranks and levers, is that they are so interlocked with each other that whenever the attendant (human and fallible), by inadvertence, siezes the wrong lever, he finds it locked. Thus he cannot set the signals to clear for a

train to move until the switches are all in correct position. The breakage of an actuating rod leading to a signal would leave the signal to the action of gravity, and it is so made and weighted that it would fall to the danger position, and prevent the moving of the train until attended to. Inaction, incapacity or sleep of attendant simply causes delay. Signals not being cleared, trains are stopped.

Such appliances instated at crossings, would evidently provide safety next to absolute; and admit of the passing of trains at nearly, if not quite full speed—indeed at full speed when a rail-junction reversible frog for closing up the rail gaps shall come to be operated along with the derailing switches. Then no stops would be required at crossings except as two trains, at comparatively long intervals, would happen to require the crossing at nearly the same time. Then the signals and derailing switches would stand against that one which was a moment behind the other in announcing its arrival. It will then necessarily tarry

till the first has passed, when the releasing of the "detector bar" will enable the man in the tower to turn the signals and switches just in use, back to the danger ; thus unlocking the intersecting lines, switches and signals, so that the second train can be passed.



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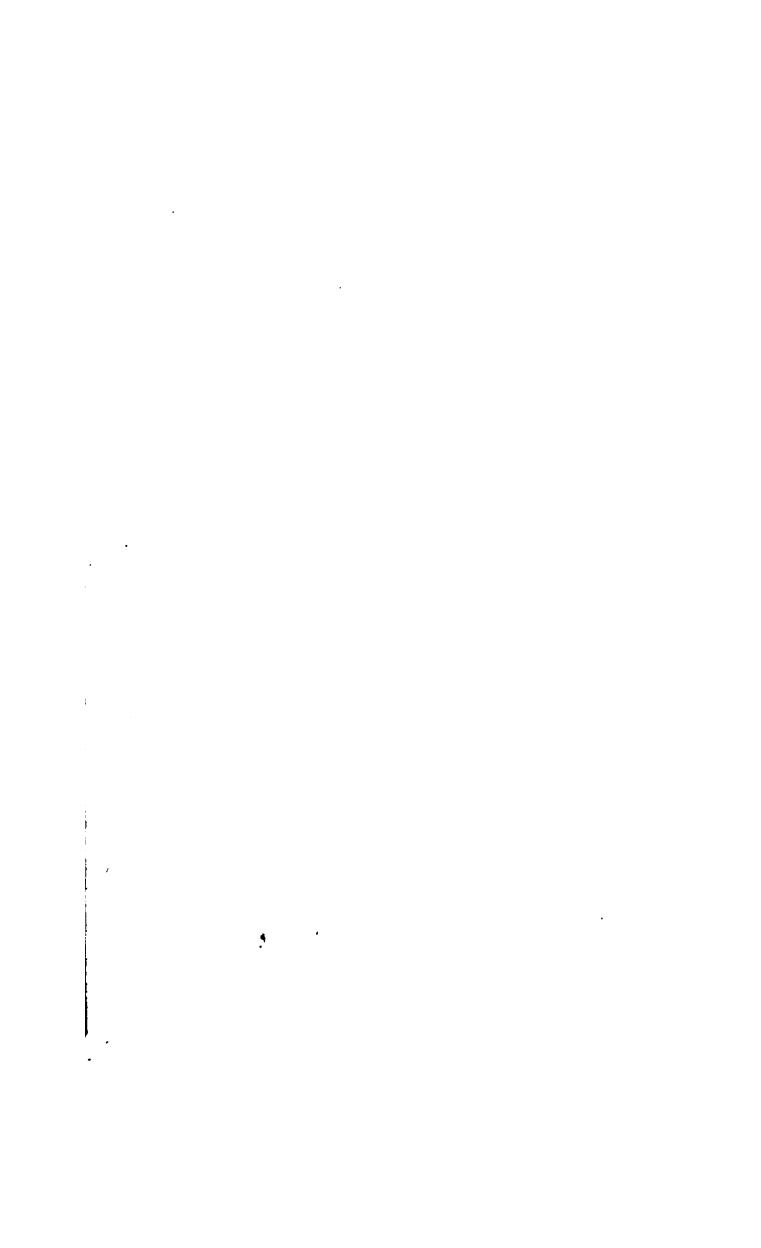
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